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LATENT HEAT STORAGE MATERIAL EVALUATION BASE ON AHP AND TOPSIS FOR LOW TEMPERATURE SOLAR HEATING APPLICATIONS

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ABSTRACT

The present study is concentrated on ranking of the chosen latent heat storage materials for low temperature solar heating applications. Multi attribute strategies like analytic hierarchy methodology and TOPSIS are used to evaluate the ranks of the selected materials. The latent heat storage materials are handpicked supported high latent heat of fusion and high specific heat at solid and liquid state, low cost and non toxic. The chosen materials might observe the properties in the literature. All the properties such as latent heat of fusion, sensible heat at solid and liquid, thermal conductivity at solid and liquid state, density at solid and liquid state and degree of super cooling are taken under consideration to rank the chosen materials.

KEYWORDS: Analytic Hierarchy Process (AHP), Technique as Order Preference by Similarity to Ideal Solution (TOPSIS), Thermo Physical Properties, Latent Heat Storage Materials

INTRODUCTION

In the present study it is chosen phase transition materials like solid to liquid transition in the temperature vary as 40-80^{o}C. The selected temperature vary is best suited for textile industries. In textile industries hot water is required to perform all the operations like drying, bleaching, laundering etc.[1]. As an example, egg powder making plant requires the hot water in the temperature vary to perform the various stages of process such as washing, pasturing, fermenting. Particularly, just in case of food products like oats, wheat etc are required hot air within the temperature vary to keep up drying rate as per the quality specification of wetness content.

In general, the choice of acceptable latent heat storage material could be a key role for an application to store the heat. Particularly, latent heat storage materials are large variety of accessible groups having multiple characteristics. These groups might not to satisfy all the facets such as thermo physical properties, economical viability, sustainability, and chemical properties. Because, each group has sure benefits and drawbacks and conjointly heap of materials are provided in the open literature [2, 3, 4]. Hence, there's at the most have to be compelled to choose best material for an intended application.

Particularly, Researchers targeted on the relative prominences of those groups such as paraffins, fatty acids, and salt hydrate materials for low temperature solar heating applications. Paraffins are two different types of groups one is technical grade paraffins, other is research grade paraffins. Techincal grade paraffins are factory made by numerous makers and also the list of accessible materials and their thermo physical properties of the technical grade paraffins are provided by abhat [2]. Research grade paraffins contain n variety of carbon atoms. It's going to be varies by varied the

quantity of carbon atoms within the every group. Normally, most of the technical grade paraffins exhibits two phase transitions. The primary phase transition is solid to solid that is a smaller amount than 2^{o}C corresponding solid – liquid phase transition is incredibly giant ≥ 14^{o}C. On the opposite hand research grade paraffin exhibits solid to liquid phase transition in a very slim temperature vary, but this group is additional expensive than technical grade paraffins [5]. From technical grade paraffin two attractive phase change materials like p116 wax, paraffin wax (58-60^{o}C) shows high latent heat of fusion and high specific heat, and low cost. However, easy of the provision of paraffin wax (58-68^{o}C) compared to p116 wax.

Different group like fatty acids, namely, myrisitic acid, hexadecanoic acid, and octadecanoic acid in a very temperature vary 50- 70^{o}C of solar heating applications has been performed by Hasan and Sayigh [6]. It absolutely was according that the fatty acids exhibit around 100% volume growth once heated from room temperature to 80^{O}C. They have also attractive features that create them as a latent heat storage material like an appropriate transition temperature vary, high latent heat of fusion and high chemical stability at numerous heating and cooling cycles. Sari [7] studies thermal stability at numerous thermal cycles of some fatty acids like octadecanoic acid, lauric acid, tetradecanoic acid, hexadecanoic acid. The results show that everyone the investigated fatty acids have a decent thermal stability. Supported higher than aspects, fatty acids like hexadecanoic acid, tetradecanoic acid, octadecanoic acid, lauric acid also can be evident to use during this temperature vary for an intended application.

Canbazoglu et al. [8] conducted experiments on two systems one is traditional open loop passive solar water utility and second one is combined sodium thiosulfate pentahydrate latent heat storage material based thermal energy storage system with a conventional system. It absolutely was discovered that the heat energy storage material primarily based conventional solar system led to a rise in water temperature by 3.45 times over the traditional system. Theoretically it absolutely was examined by numerous different salt hydrate materials like zinc nitrate hexa hydrate, disodium hydrogen dodecahydrate, calcium chloride hexahydrate, and sodium sulfate dechydrate on an equivalent solar water utility. It absolutely was found that the best solar thermal energy storage performance of salt hydrate materials like hydrogen phosphate dodecahydrate and sodium sulfate decahydrate. Supported this study it's discovered that salt hydrates are appropriate for various solar heating applications. Salt hydrate materials like Sodium thiosulfate penta hydrate, and sodium acetate trihydrate shows temperature within the selected temperature vary and also low degree of super cooling, moreover, sodium acetate trihydrate has highest latent heat of fusion and high specific heat compared to Sodium thiosulfate penta hydrate.

From the above literature it is observed that paraffin wax (58-60^{o}C), palmitic acid, lauric acid, myristic acid, stearic acid and sodium acetate trihydrate having high latent heat of fusion and specific heat and low cost and non toxic that makes an attractive for an intended application. Hence, in preliminary study it is procured high purity materials and studied melting point, latent heat of fusion, specific heat at solid, specific heat at liquid state through differential scanning calorimetry [14]. Other properties like thermal conductivity at solid, thermal conductivity at liquid state, density at solid, density at liquid state are chosen from the literatures. Other important property like degree of super cooling is investigated through heating and cooling cycle in a glass tube apparatus. The obtained values are used for ranking of the selected materials through multi attribute methods.

Multi attribute methods have been widely used in ranking or optimal selection of alternatives from a finite number of alternatives with respect to multiple attributes. Over the past decades there are many ways are developed, despite of

these, there is no one best methodology for general multi attribute problems. Since different ways offer different results at different input conditions. A lot of literature shows that on comparison of various ways for various applications. Yeh [9] investigated important specifications of assorted multi attribute ways. In spite of the mentioned specifications, he noted that there's nobody best methodology as a general methodology and satisfactoriness of a way is predicated on the particular problem domain characteristics and its knowledge set. Belton [10] chosen two completely different ways. Numerous input assumptions are developed (own criteria, weights, scores) for every of the ways then compared the whole score of the multi attribute problem. It absolutely was found wider scatter and a poor correlation between the scores obtained by every of the ways. Gershon et al. [11] States that different multi attribute ways yields different results when applied to same problem under same assumptions. Those studies deals with different input conditions like uses of various weights and uses of variable scale factors that result in different outcome. Raju and Pillai [12] addressed same input conditions like same weights and same scaling factors are through of the problem and approached completely different ways. The obtained results show that initial rank is same for all the ways.

Rathod et al. [13] addressed two ways TOPSIS and fuzzy TOPSIS for optimum choice of heat storage materials of domestic solar water utility. They approached each the ways with same weights for ranking of the materials. Weights are determined through AHP methodology. They conjointly mentioned that the chosen ways are viable in determination of choice of phase change material for an application. The most objective of this study is to see the optimum material of the chosen latent heat storage materials. Therefore, within the study the properties like latent heat of fusion, specific heat at solid and liquid state, density, thermal conductivity at solid and liquid state and degree of super cooling are chosen from the literature. This study address two multi attribute ways like AHP, TOPSIS for ranking of the chosen materials. In this study same weights are adopted for the each ways.

DETAILS OF EXPERIMENTATION

Materials

In the present work the following latent heat storage materials namely, palmitic acid, myristic acid, stearic acid, lauric acid, sodium acetate trihydrate and paraffin wax are selected and their properties are provided in table 1.

DETERMINATION OF RANKING OF THE SELECTED MATERIALS THROUGH AHP AND TOPSIS METHOD

AHP (Analytical Hierarchy Process)

Step 1: objective function contains the attributes and alternatives is as follows

Table 1: Properties of Selected Latent Heat Storage Materials

Materials	Material Selection Attributes							
	ΔH	C_{Ps}	C_{pl}	ρ_S	ρ_l	k_s	k_l	T^oC
Paraffin wax	180.1	2.35	3.25	850	775	0.2	0.15	0
Stearic acid	170.46	2.86	2.1	1080	1150	0.18	0.172	0
Palmitic acid	212.45	2.15	2.94	942	862	0.16	0.159	0
Myristic acid	228.2	3.29	2.65	990	861	0.15	0.15	0
Lauric acid	177.4	2.117	1.53	1007	862	1.6	0.147	0
Sodium acetate trihydrate	264.18	2.008	2.93	1450	1280	0.7	0.4	30

Step 2: construct the pair wise matrix that compares the attributes and values are placed into a reciprocal matrix. The reciprocal matrix is used to calculate the principle eigen vectors which represents the criteria weights. This technique

was developed by Saaty [15] and it is utilized as shown in three steps below

- **Multiply the Elements Within Each Row of a Matrix**

Table 2

Materials	Weights of the Criteria is Calculated by Using AHP Method								Multiplied Rows
	ΔH	C_{Ps}	C_{pl}	ρ_S	ρ_l	k_s	k_l	T°C	
ΔH	1	5	5	7	7	5	5	9	275625
C_{Ps}	0.20000	1	1	5	5	3	3	7	315
C_{pl}	0.20000	1	1	5	5	3	3	7	315
ρ_S	0.1429	0.20000	0.20000	1	1	0.20000	0.20000	3.00000	0.000685714
ρ_l	0.1429	0.20000	0.20000	1	1	0.20000	0.20000	3.00000	0.000685714
k_s	0.20000	0.3333	0.3333	5	5	1	1	5	2.777777778
k_l	0.20000	0.3333	0.3333	5	5	1	1	5	2.777777778
T°C	0.1111	0.1429	0.1429	0.3333	0.3333	0.20000	0.20000	1	1.00781E-05

- **For Each Row, Take the nth Root of the Multiplied Product**

Table 3

Materials	Multiplied Rows	Nth Root
ΔH	275625	4.78674
C_{Ps}	315	2.052527
C_{pl}	315	2.052527
ρ_S	0.000685714	0.40227
ρ_l	0.000685714	0.40227
k_s	2.777777778	1.136219
k_l	2.777777778	1.136219
T^{o}C	1.00781E-05	0.237368

- **Normalize the nth Root Values by Dividing by the Sum**

Table 4

Materials	nth Root	Priorities
ΔH	4.78674	0.392158
C_{Ps}	2.052527	0.168155
C_{pl}	2.052527	0.168155
ρ_S	0.40227	0.032956
ρ_l	0.40227	0.032956
k_s	1.136219	0.093086
k_l	1.136219	0.093086
T^{o}C	0.237368	0.019447

Step 4: In this problem consistency check is used to ensure that it has not violated transitivity. The consistency check uses consistency values derived from random judgments in a four step process, outline is given below. Consistency values are developed by saaty [15]

Consistency Values

Table 5

Attributes	3	4	5	6	7	8	9	10
CV(RI)	0.52	0.89	1.11	1.25	1.35	1.41	1.45	1.49

- Sum the Elements in the Each Column and Multiply by the Principle Eigen Vectors

Table 6

Materials	Weights of the Criteria is Calculated by Using AHP Method								Priorities
	ΔH	C_{ps}	C_{pl}	P_s	P_l	K_s	K_l	T°c	
ΔH	1	5	5	7	7	5	5	9	0.392158
C_{Ps}	0.20000	1	1	5	5	3	3	7	0.168155
C_{pl}	0.20000	1	1	5	5	3	3	7	0.168155
ρ_S	0.1429	0.20000	0.20000	1	1	0.20000	0.20000	3.00000	0.032956
ρ_l	0.1429	0.20000	0.20000	1	1	0.20000	0.20000	3.00000	0.032956
k_s	0.20000	0.3333	0.3333	5	5	1	1	5	0.093086
k_l	0.20000	0.3333	0.3333	5	5	1	1	5	0.093086
T°C	0.1111	0.1429	0.1429	0.3333	0.3333	0.20000	0.20000	1	0.019447
Sum	**2.19683**	**8.20952**	**8.20952**	**29.3333**	**29.3333**	**13.60000**	**13.60000**	**40.00000**	
sum*priorities	0.861503	1.380475	1.380475	0.966721	0.966721	1.265968	1.265968	0.777865	

- Calculate the Y_{max} by summing the calculated Sum*priorities values

  Y_{max} = 8.865694234

- Calculate the consistency index using

  CI=Y_{max}-n/(n-1)=8.865694234-8/(8-1)=0.123670605

- Calculate consistency ratio using CR = CI/CV=0.123670605/1.41=0.087709649

Saaty [15] suggested that a CR of 'o' infers perfect consistency while a CR above 0.1 is considered inconsistent. The threshold for inconsistency is 0.1 which is considered very strict and impractical or not acceptable.

Step 5: The quantitative values of material selection attributes which are given in the above table and are normalized.

Table 7

Materials	Normalized Values of Material Selection Attributes							
	ΔH	C_{ps}	C_{pl}	P_s	P_l	K_s	K_l	T°c
Paraffin wax	0.353229141	0.382924859	0.504106855	0.324226496	0.322108662	0.112322333	0.282730145	0
Stearic acid	0.334322262	0.466027701	0.325730583	0.411958371	0.477967692	0.1010901	0.324197233	0
Palmitic acid	0.416677019	0.350335509	0.456022817	0.359319246	0.358267957	0.089857867	0.299693954	0
Myristic acid	0.447567407	0.53609	0.41104	0.377628507	0.357852333	0.08424	0.28273	0
Lauric acid	0.347933646	0.34496	0.23732	0.384113037	0.358267957	0.89858	0.27708	0
Sodium acetate trihydrate	0.518134784	0.3272	0.4545	0.553092257	0.531998822	0.393128167	0.753947055	1

Step 6: Relative normalized weights of the material selection attributes are calculated. The obtained weights are presented.

Table 8

w1	**0.399935738**
w2	0.171490161
w3	0.171490161
w4	0.033609983
w5	0.033609983
w6	0.094931988
w7	0.094931988
w8	0.019832285

Step 7: normalized weights of the material selection attributes are calculated. Obtained normalized weights of the material selection attributes are presented.

Step 8: The overall performance scores for the alternatives are obtained by multiplying the Relative normalized weight of each attribute with its corresponding normalized weight value for each alternative and summing overall the attributes material are presented.

Table 9

Materials	Score	Rank
Paraffin wax	0.352612599	5
`Stearic acid	0.339769947	6
Palmitic acid	0.353984192	4
Myristic acid	0.400979537	2
Lauric acid	0.375564353	3
Sodium acetate trihydrate	0.48787601	1

TOPSIS

Step 1: The objective is to evaluate the six alternative materials and the attributes are latent heat of fusion (ΔH), specific heat at solid state (C_{Ps}), specific heat at liquid state (C_{pl}), density at solid state (ρ_S), density at liquid state (ρ_l), thermal conductivity at solid state (k_s), thermal conductivity at liquid state (k_l) and degree of super cooling (T^oC). For this particular material selection problem, ΔH, C_{Ps}, C_{pl}, ρ_S, ρ_l,$k_{s,,}$ k_l are considered as beneficial attributes and T^oC is considered as non beneficial attribute.

Step 2: objective function subjected to attributes and alternatives, which are given in table

Table 10

Materials	Material Selection Attributes							
	ΔH	C_{ps}	C_{pl}	P_s	P_l	K_s	K_l	T^oc
Paraffin wax	180.1	2.35	3.25	850	775	0.2	0.15	0
Stearic acid	170.46	2.86	2.1	1080	1150	0.18	0.172	0
Palmitic acid	212.45	2.15	2.94	942	862	0.16	0.159	0
Myristic acid	228.2	3.29	2.65	990	861	0.15	0.15	0
Lauric acid	177.4	2.117	1.53	1007	862	1.6	0.147	0
Sodium acetate trihydrate	264.18	2.008	2.93	1450	1280	0.7	0.4	30

Step 3: The quantitative values of the material selection attributes are normalized, which are given in table

Table 11

Materials	Normalized Values of Material Selection Attributes							
	ΔH	C_{ps}	C_{pl}	P_s	P_l	K_s	K_l	T^oc
Paraffin wax	0.353229141	0.382924859	0.504106855	0.324226496	0.322108662	0.112322333	0.282730145	0
Stearic acid	0.334322262	0.466027701	0.325730583	0.411958371	0.477967692	0.1010901	0.324197233	0
Palmitic acid	0.416677019	0.350335509	0.456022817	0.359319246	0.358267957	0.089857867	0.299693954	0
Myristic acid	0.447567407	0.53609	0.41104	0.377628507	0.357852333	0.08424	0.28273	0
Lauric acid	0.347933646	0.34496	0.23732	0.384113037	0.358267957	0.89858	0.27708	0
SAT	0.518134784	0.3272	0.4545	0.553092257	0.531998822	0.393128167	0.753947055	1

Step 4: Relative normalized weights of the selected material attributes, AHP weights are considered to this method. The obtained relative weighted normalized material attributes are presented in table.

Table 12

w1	**0.399935738**
w2	0.171490161
w3	0.171490161
w4	0.033609983
w5	0.033609983
w6	0.094931988
w7	0.094931988
w8	0.019832285

Step 5: The weighted normalized material attributes are presented in table

Table 13

Materials	Weighted Normalized Values of Material Selection Attributes							
	ΔH	C_{ps}	C_{pl}	P_s	P_l	K_s	K_l	T°c
P-wax	0.141268957	0.065667846	0.086449366	0.010897247	0.010826067	0.010662982	0.026840135	0
Stearic acid	0.133707421	0.079919165	0.05585959	0.013845914	0.016064486	0.009596684	0.030776688	0
Palmitic acid	0.166644031	0.060079093	0.078203426	0.012076714	0.01204138	0.008530386	0.028450543	0
Myristic acid	0.178998201	0.09193	0.07049	0.012692088	0.012027411	0.00800	0.02684	0
Lauric acid	0.139151099	0.05916	0.04070	0.012910032	0.01204138	0.08530	0.02630	0
SAT	0.207220617	0.0561	0.0779	0.018589421	0.017880471	0.037320438	0.071573693	0.019

Step 6: obtain ideal and negative ideal solution are calculated, which are presented in table

Table 14

Positive		Negative	
$V_{\Delta H}^{+}$	0.207220617	$V_{\Delta H}^{-}$	0.133707421
V_{CPs}^{+}	0.091934984	V_{CPs}^{-}	0.056111078
V_{Cpl}^{+}	0.086449366	V_{Cpl}^{-}	0.040697701
$V_{\rho S}^{+}$	0.018589421	$V_{\rho S}^{-}$	0.010897247
$V_{\rho l}^{+}$	0.017880471	$V_{\rho l}^{-}$	0.010826067
V_{ks}^{+}	0.085303859	V_{ks}^{-}	0.007997237
V_{kl}^{+}	0.071573693	V_{kl}^{-}	0.026303332
V_{ToC}^{+}	0	V_{ToC}^{-}	0.019832285

Step 7: obtain separation measures, which are presented in table

Table 15

S_1^{+}	**0.112786834**
S_2^{+}	0.117924022
S_3^{+}	0.102759599
S_4^{+}	0.095381678
S_5^{+}	0.094034196
S_6^{+}	0.063651657
S1-	0.051404643
S2-	0.035337405
S3-	0.053928909
S4-	0.067973742
S5-	0.080087906
S6-	0.09904129

Step 8: relative closeness to ideal solution is calculated, which are presented in table.

Table 16

Materials	Score	Rank
Paraffin wax	0.313077413	5
Stearic acid	0.230569465	6
Palmitic acid	0.344179095	4
Myristic acid	0.416109499	3
Lauric acid	0.459952556	2
Sodium acetate trihydrate	0.608762037	1

RESULTS AND DISCUSSIONS

AHP Analysis

AHP requires the input of pair wise comparisons to calculate attribute weights. Due to the nature of pairwise comparisons, requiring a selection for every possible pair of criteria rather than a single selection for each criterion, the analysis required sixteen pair wise comparisons to determine the criteria weights. The pairwise comparisons provided were valid in terms of transitivity. As the consistency checker indicated that the consistency ratio was below 0.1 and hence pair wise comparison is consistency to determine the criteria weights. The criteria weights, which sum to 1 are shown as percentage values in figure 1.

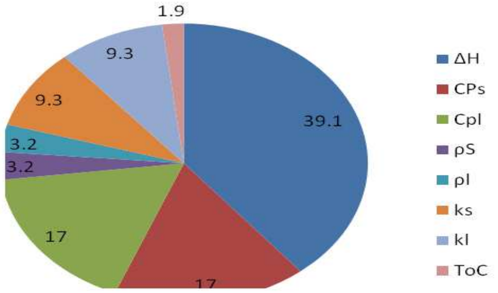

Figure 1: AHP Attribute Weights of Selected Materials

From figure 1 it can be concluded that ΔH was prioritized followed by specific heat at solid and liquid state and thermal conductivity at solid and liquid state. The remaining attributes density at solid and liquid state, degree of super cooling was deemed to be much less important in this analysis. The obtained results are presents in a chart which is shown in figure 2

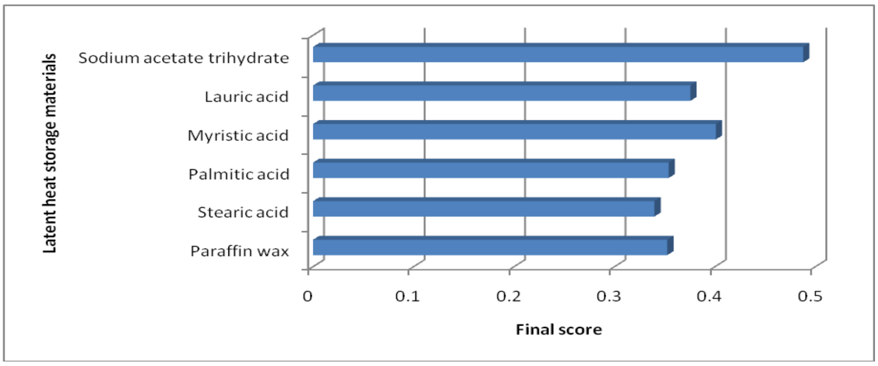

Figure 2: Final Score of AHP Analysis

Figure shows that sodium acetate trihydrate achieved that the highest overall score. This was due to high latent heat, high specific heat, high thermal conductivity being the most influence attributes. Second highest latent heat storage material is myristic acid and followed by lauric acid. Lowest overall score achieved by stearic acid.

TOPSIS Analysis

In this analysis same weights are used as that of the AHP method. From AHP weights it can be concluded that ΔH was prioritized (39.1%) followed by specific heat at solid (17%) and liquid state (17%) and thermal conductivity at solid (9.3%) and liquid state (9.3%). The remaining attributes density at solid (3.2%) and liquid state (3.2%), degree of super cooling (1.9%) was deemed to be much less important in this analysis. The total score of the weight is equal to one. The obtained results of TOPSIS method which presents in a chart which is shown in figure 3

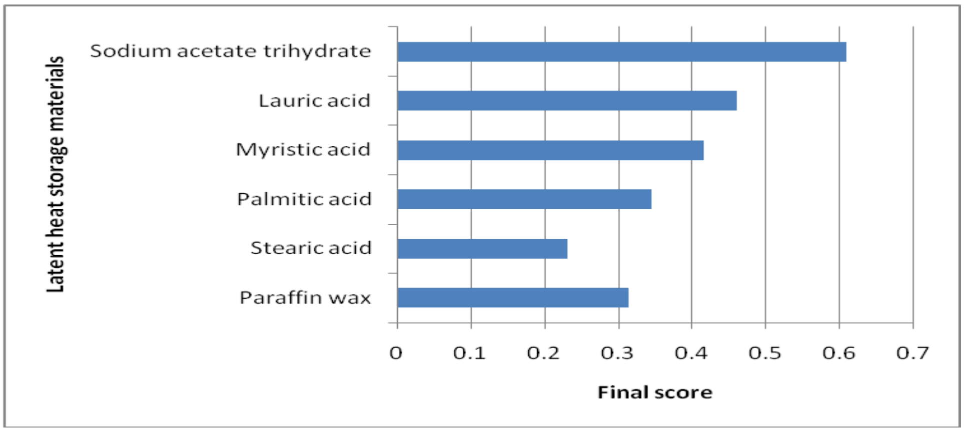

Figure 3: Final Score of TOPSIS Analysis

Figure 3 shows that sodium acetate trihydrate achieved that the highest overall score. This was due to high latent heat, high specific heat, high thermal conductivity being the most influence attributes. Second highest latent heat storage material is lauric acid and followed by myristic acid. Lowest overall score achieved by stearic acid.

CONCLUSIONS

From this study it is observed that both the methods have shown ranking of the selected materials. sodium acetate trihydrate is achieved highest score and hence sodium acetate trihydrate gives the first choice in both the methods. This material is more suitable for latent heat storage for an application. In case of AHP, Second choice gives myristic acid and followed by lauric acid whereas TOPSIS, second choice gives lauric acid and followed by myristic acid. In case of both the methods stearic acid achieved lowest score compared to other materials. And hence this material gives the last choice in both the methods.

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